

# SEE Characterization of the Samsung KM48C8000 DRAM for the SWIFT Explorer Project

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## 1 Introduction

In support of the SWIFT project, the Single Event Effects (SEE) characteristics of the Samsung KM48C8000 DRAM were measured by the JPL Radiation Effects Group [1]. All tests were carried out with heavy ion beams provided by the Texas A&M University Cyclotron Radiation Effects Facility (TAM) [2]. The cross sections for Single Event Upsets (SEU) and Multiple Bit Upsets (MBU) cross sections were measured for a statistically significant sample of devices, culled from the SWIFT flight lot, at various heavy ion linear energy transfers (LETs). Also, the stuck bit, Single Event Latchup (SEL), and Single Event Functional Interrupt (SEFI) behavior of the devices were observed. The heavy ion measurements were performed between August 20-24, 2002. This report summarizes the results of the tests.

## 2 Device

The Samsung KM48C8000 is a  $8 \times 2^{23}$  bit Fast Page CMOS 5.0 V DRAM. The two-dimensional address space is organized into  $2^{13}$  rows and  $2^{10}$  columns. More details can be obtained from the manufacturer's specification sheet, a copy of which can be found at [3].

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### 3 Radiation Facilities

The TAM cyclotron facility is detailed in the reference found above. However, a few remarks regarding the beams used are presented here. The heavy-ions provided by TAM, although possessing similar LETs, are significantly less energetic than those found in the Galactic Cosmic Ray (GCR) spectrum. As a result, the ranges of the ion beams in silicon and plastic are limited, and the package, as well as the lead-frame must be removed before testing. The JPL radiation group received the devices from Goddard already delidded.

TAM provides ions in a wide range of species and energies. However, to further increase the available LETs, the beams can be degraded with a system of foils, varying in thickness and rotation angles. The range of available LETs can be further increased by rotating the DUT, and to first order approximate the effective LET within the device ( $L_{\text{eff}}$ ) by the cosine-law,

$$L_{\text{eff}} = \frac{L_f}{\cos \theta}, \quad (1)$$

where  $L_f$  is the LET of the beam normal-incident on the part (downstream of the degrading foils).

A note must be made regarding the beam counting provided by TAM. Four scintillators are placed on the perimeter of the beam spot, slightly upstream of the target. A removable scintillator is placed in the center of the beam spot. Prior to the device under test (DUT) exposure, the ratios of the four outer scintillators to the central one are measured (axial gain). During irradiation, the central scintillator is removed (so as to not degrade the beam further) and the axial gain, along with the beam counts in the four outer scintillators are used to infer the flux incident on the DUT. See reference [2] for further details. For these tests, axial gain measurements were performed before and after each instance of DUT irradiation to monitor any drift in the axial gain. If significant drift was found, the measurement were not used in the analysis. This insures fidelity in beam counting.

### 4 Experimental Apparatus and Procedure

The testing apparatus consisted of two PCs, a HP6629A power supply, and a specialized test circuit board. One PC, running Windows, was used to operate the HP6629A, which supplied power to the test board and DUT. High-level software, developed by the JPL group, was used to remotely operate and monitor the GPIB compatible power supply, as well as logging the current consumed by the DUT. The other PC, which ran a minimized Linux kernel, exercised and evaluated the DUT's performance, using a commercial PLX PCI I/O card to interface with the test board.

The test board was mounted directly downstream of the beam pipe, with the DUT centered on the beam. For the case of heavy ions, the DUT can also be rotated to vary  $L_{\text{eff}}$  (equation 1). Because humans cannot be in close proximity to the DUT while being irradiated, a combination of commercial receiver/driver cards are used to propagate the signals along the 40 pin, 50 ft ribbon cables that physically connect the Linux PC and test board.

To measure the upset cross sections, as well as the SEL, SEFI, and stuck bit response, a minimum of 5 passes are made over the DUT's address space. A pass consists of accessing each of the  $2^{23}$  words, reading the 8 bit pattern stored, comparing it with an expected pattern, and re-writing the expected pattern. For the initial, or fill pass, the patterns read from the words are disregarded, and a known, random  $8 \times 2^{23}$  bit pattern is used to fill the memory array.

A single address is accessed at a time, in a consistent sequence. The rows and columns are incremented separately, using two loops in a nested structure. The columns are incremented the fastest due to the fact that when a word is accessed, the entire column gets refreshed. It takes about 73 s to complete an entire read/write pass which results in an approximate refresh time of 70 ms.

After the fill pass, another pass is performed, to insure bit integrity. If no bit errors are found, another pass is begun, while simultaneously opening up the beam shutter. Beam is delivered to the DUT for approximately 60 s, and the beam shutter is closed before the third pass is completed. Next, a fourth pass is performed, and the total number of errors due to the presence of ionizing radiation is the sum of errors in pass three and four. Finally, a fifth pass is made to check for stuck bits. For SEL and other phenomena with relatively small cross sections (or in instances when the flux delivered by the cyclotron is small enough that it takes multiple passes to incur a statistically significant number of upsets), usually up to seven or eight passes are performed while delivering beam to the part to allow for a larger fluence. When errors are found, the specific address, as well as the pattern read and expected are logged. The JPL group wrote the low-level software that performed the reading/writing to the addresses, as well as the error checking and logging. The method of determining the instantaneous beam flux and integration to obtain the total fluence is facility dependent and details can be found in the references.

## 5 Analysis

The upset cross sections are calculated using equation 2,

$$\sigma = \frac{N}{\Phi}, \quad (2)$$

where  $N$  is the total number of upsets and  $\Phi$  is the fluence,

$$\Phi = \int_0^T \phi(t) dt, \quad (3)$$

where  $\phi(t)$  is the instantaneous flux of the beam and  $T$  is the duration of the run.

The current consumed by the DUT is continuously monitored by the software controlling the power supply. A SEL event is characterized by significant jump in the current. These devices typically use around 17 mA and the latchup threshold was set at 50 mA. The software can cycle the power in  $< 1$  s. A SEFI event is characterized by a large percentage of the device failing, typically on the order of  $10^6$  bits.

## 6 Results

### 6.1 Upset Cross Section Results

Three types of cross sections were calculated from the heavy ion data: the bit upset cross section,  $\sigma_{\text{bit}}$ , where  $N$  in equation 2 is defined as the total number of bits upset, the address upset cross section,  $\sigma_{\text{add}}$ , where  $N$  is defined as the total number of words with at least a single bit upset, and the multiple bit upset cross section,  $\sigma_{\text{mbu}}$ , where  $N$  is defined as the number of words with multiple ( $\geq 2$ ) upset bits. It is assumed that if multiple bits are upset within a single 8 bit word, the source of the upsets must be a single ion. This assumption is justified considering the total number of upset bits is typically between 10000 and 50000. The probability for two separate ions (out of 50000) to strike the same word (out of  $2^{23}$ ) is minimal.

The three variants of cross sections, as a function of LET were measured for 3 delidded parts, labeled Part 752, 801, and 804. The respective results are found in Tables 1, 2, and 3. Note that due to the large numbers of errors observed, the statistical errors are  $< 1\%$  and the frequent monitoring of the axial gain minimized the systematic beam normalization error, thus no errors reported.

Due to the similarity in the 3 parts, the respective cross sections can be combined to arrive at an “average” measurement for each of the 3 cross sections defined above. The three resulting “average” measurements are shown in Figures 1, 2, and 3. Also shown in the figures is a the Edmonds curve (equation 4 [4]) which is fit to each of the cross sections,

$$\sigma(L_{\text{eff}}) = A \cdot e^{-\frac{B}{L_{\text{eff}}}}, \quad (4)$$

where  $A$  and  $B$  are the two fitting parameters. The values of the fitting parameters for each cross section curve is given in Table 4.

### 6.2 SEL and SEFI Results

For latchup behavior (SEL), Parts 801 and 814 were observed to latchup with and LET of  $56.0 \text{ MeV cm}^2 / \text{mg}$ , while Part 752 did not latch until and LET

LET (MeV cm <sup>2</sup> /mg)	$\sigma_{\text{bit}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{add}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{mbu}}$ (cm <sup>2</sup> /device)
1.77	1.06E-3	1.06E-3	1.07E-7
5.57	2.13E-2	2.12E-2	9.95E-5
6.47	4.56E-2	4.55E-2	1.37E-4
7.90	8.94E-2	8.90E-2	3.58E-4
11.20	1.79E-1	1.78E-1	9.08E-4
20.00	4.20E-1	4.17E-1	3.79E-3
23.10	4.99E-1	4.87E-1	1.23E-2
28.30	6.20E-1	5.70E-1	4.78E-2
39.60	8.73E-1	8.06E-1	6.12E-2
45.70	1.07E0	9.82E-1	8.75E-2
56.00	1.33E0	1.13E0	1.78E-1
79.17	2.07E0	1.62E0	4.16E-1

Table 1: The bit, address, and multiple bit upset cross sections measured for Part 752.

LET (MeV cm <sup>2</sup> /mg)	$\sigma_{\text{bit}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{add}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{mbu}}$ (cm <sup>2</sup> /device)
1.77	7.67E-4	7.67E-4	4.78E-7
5.57	8.26E-3	8.25E-3	5.40E-6
6.47	2.48E-2	2.48E-2	1.61E-5
7.92	6.89E-2	6.88E-2	9.41E-5
11.20	1.58E-1	1.57E-1	5.66E-4
20.00	3.45E-1	3.37E-1	2.03E-2
23.10	4.28E-1	4.17E-1	9.03E-3
28.30	5.86E-1	5.48E-1	2.75E-2
39.60	8.29E-1	7.62E-1	5.90E-2
45.70	1.03E0	9.16E-1	9.82E-2
56.00	1.23E0	1.05E0	1.60E-1
79.17	1.84E0	1.43E0	3.61E-1

Table 2: The bit, address, and multiple bit upset cross sections measured for Part 801.

LET (MeV cm <sup>2</sup> /mg)	$\sigma_{\text{bit}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{add}}$ (cm <sup>2</sup> /device)	$\sigma_{\text{mbu}}$ (cm <sup>2</sup> /device)
5.60	1.60e-2	1.60e-2	1.46e-5
6.47	3.99e-2	3.98e-2	8.52e-5
7.92	8.34e-2	8.31e-2	2.77e-4
11.20	1.79e-1	1.78e-1	1.08e-3
20.00	3.60e-1	3.56e-1	3.58e-3
23.10	4.34e-1	4.30e-1	3.91e-3
28.30	6.45e-1	5.99e-1	3.78e-2
39.60	8.93e-1	7.75e-1	1.18e-1
45.70	1.13e0	9.15e-1	2.14e-1
56.00	1.29e0	9.54e-1	3.34e-1
79.20	2.02e0	1.19e0	6.58e-1

Table 3: The bit, address, and multiple bit upset cross sections measured for Part 814.

Cross Section	$A$ (cm <sup>2</sup> )	$B$ (mg / MeV cm <sup>2</sup> )
Bits	2.18	27.1
Address	1.72	23.7
Multiple Bit	0.30	50.1

Table 4: The values of the Edmonds fitting parameters (equation 4) for the bits ( $\sigma_{\text{bit}}$ ), address ( $\sigma_{\text{add}}$ ), and multiple bit ( $\sigma_{\text{mbu}}$ ) heavy ion upset cross sections.

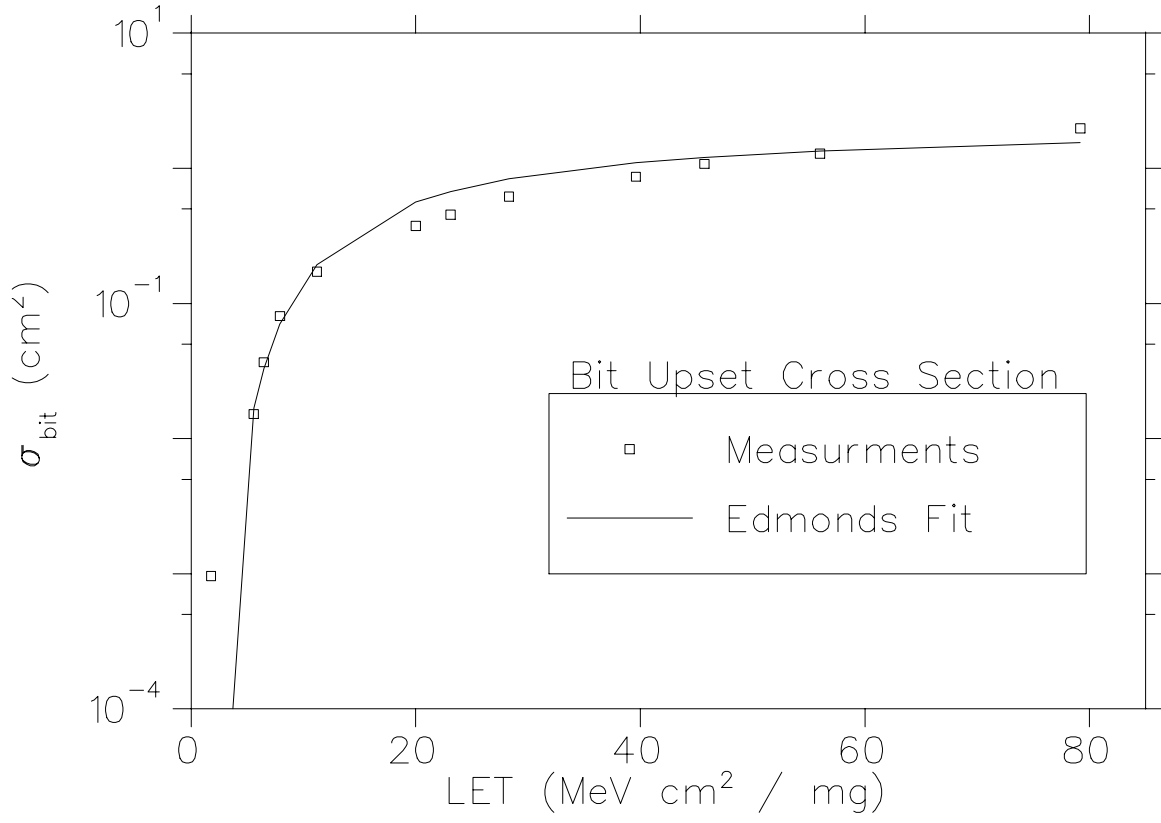


Figure 1: The “average” bit cross section, along with the Edmonds fit,  $A = 2.18 \text{ cm}^2$ ,  $B = 27.1 \text{ mg / MeV cm}^2$ .

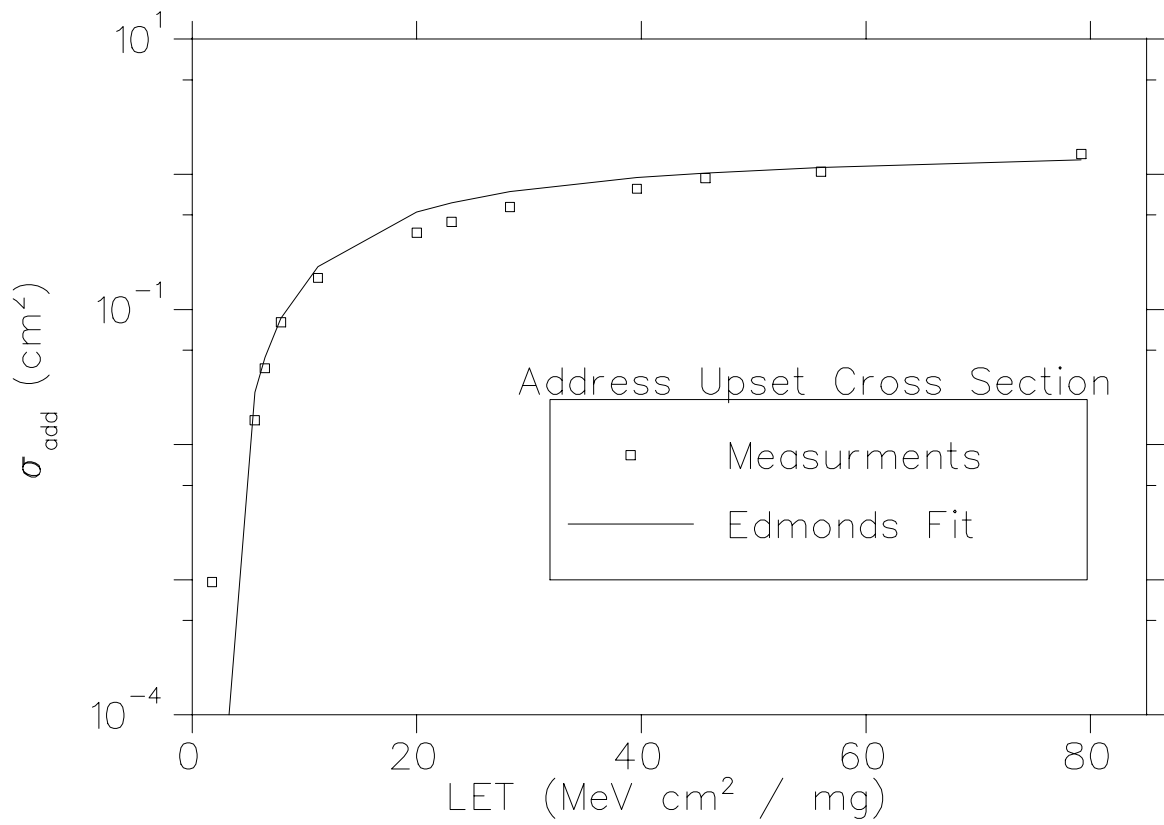


Figure 2: The “average” address cross section, along with the Edmonds fit,  $A = 1.72 \text{ cm}^2$ ,  $B = 23.7 \text{ mg} / \text{MeV cm}^2$ .

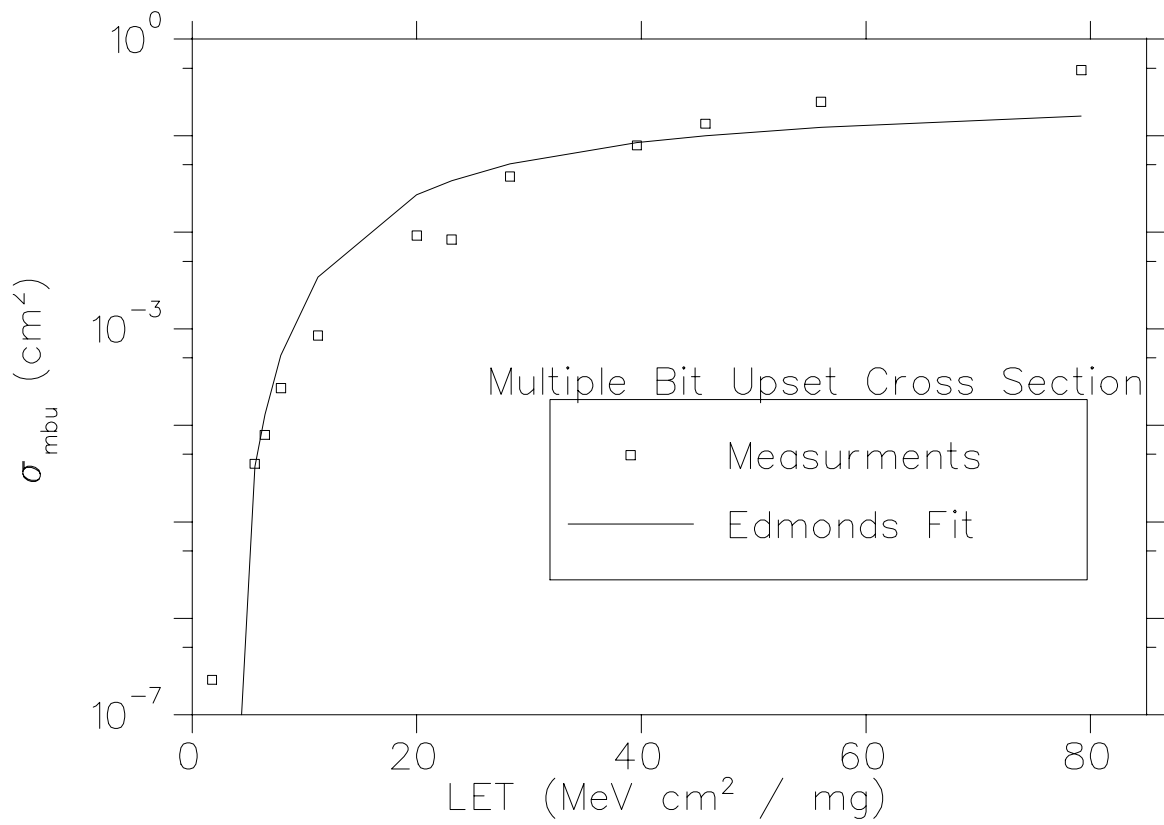


Figure 3: The “average” multiple bit cross section, along with the Edmonds fit,  $A = 0.30 \text{ cm}^2$ ,  $B = 50.1 \text{ mg} / \text{MeV cm}^2$ .

of  $79.2 \text{ MeV cm}^2 / \text{mg}$ . Also Part 801 experienced a single SEFI at an LET of  $79.2 \text{ MeV cm}^2 / \text{mg}$ . This was the only part and the only instance of a SEFI observed throughout the entire test. There is no accurate method to determine the fluence that was delivered to the DUT before either of these two error modes occurred, thus no cross section is calculated. Suffice to say, both of these modes are extremely rare, and any cross section would be very low. No stuck-bits were observed with the heavy ion beams.

## 7 Conclusions

This report summarizes the SEE test results for the Samsung KM48C8000  $8 \times 8\text{M}$  DRAM. Heavy ion tests were performed on three devices from the flight lot. The effective LET was varied between 1.77 and  $79.2 \text{ MeV cm}^2/\text{mg}$ . All the devices were delidded to expose the sensitive volume to the beam. Bit, address, and multiple bit upset cross sections are tabulated and parameterized curves are given that model the data. Two of the three tested devices were observed to latch at an LET of  $56.0 \text{ MeV cm}^2 / \text{mg}$ , while the third did not latch until an LET of  $79.2 \text{ MeV cm}^2/\text{mg}$ . One of the devices experienced a single SEFI at an LET of  $79.2 \text{ MeV cm}^2/\text{mg}$ . The latches were mitigated within 1 s and the devices were not permanently damaged. No ion induced stuck bits were observed.

## References

- [1] <http://parts.jpl.nasa.gov>
- [2] <http://cyclotron.tamu.edu/ref/>
- [3] <http://www.samsung.com>
- [4] L. D. Edmonds, "SEU Cross Sections Derived from a Diffusion Analysis," IEEE Trans. Nucl. Sci., no. 6, pp. 3207-3217, Dec. 1996.